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REARRANGEMENT PROCEDURES IN REGENERATIVE MULTIBEAM MOBILE COMMUNICATIONS SATELLITES WITH FREQUENCY REUSE

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ABSTRACT

After a short overview on the European tendencies about a Land Mobile Satellite Service, this paper describes an advanced system architecture, based upon multiple spot-beams and On-Board Processing, capable of providing message and voice services over a wide European coverage, including some North-Africa and Middle-East countries. A remarkable problem associated to spot-beam configurations is the requirement for flexibility in the capacity offer to the various coverage areas. This means incorporating procedures for changing the on-board modulator-to-spot associations, respecting the constraints imposed by frequency reuse. After discussing the requirements of the rearrangement procedure, an on-purpose algorithm is presented. This paper is derived from work performed on contract to ESA, the European Space Agency.

1. INTRODUCTION

A Land-Mobile Satellite System (LMSS) in Europe can complement the Pan-European terrestrial cellular network (usually referred to as "GSM" network), covering the regions not served by it. An important market is represented by transportation companies, which already expressed the need of communicating with lorries travelling in Europe and neighbouring countries. The integration is doubtful in the short and medium run, because of the very different technical solutions among which the use of different frequency bands (around 900 MHz for GSM and around 1.5 GHz for the LMSS) is not a minor item.

Two basic solutions are currently investigated: the Standard-C (designed in the INMARSAT context) and the PRODAT, developed by ESA. A major objective is to supply the voice service in the second or third-generation LMSS. Several studies have been conducted by ESA to determine the required technologies for the advanced configurations of a LMSS capable of satisfying medium traffic demands (about 3000 erlang).

A study by TELESPAZIO with ANT, CSELT and DORNIER Systems as subcontractors [ESA 1983] led to the following main conclusions:

- 19 spot beams for mobile station coverage, with 37 dB antenna gain are enough for Europe and neighbouring countries

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- On-Board Processing (OBP) is needed for providing routing functions, Demand Assignment (DA) and reconfiguration capability
- frequency reuse is a must, since the frequency band for LMSS is limited to 23 MHz (WARC '87) against a requirement of 28.8 MHz (7.5 kHz with QPSK modulation for each 9.6 kbps voice channel).

2. AN ADVANCED ARCHITECTURE FOR A EUROPEAN LMSS

The system topology is based upon several (10 to a maximum of 100) Fixed Stations (FS) containing gateway functions with the terrestrial network and a multitude of Mobile Stations (MS) [Kriedte et alii, 1985]. Two links can be distinguished, a Forward Link (FL) for FS-to-MS communications and a Return Link (RL) in the opposite way: each comprises an Up (U) and Down (D) section so that four links (FUL, FDL, RUL and RDL) can be identified.

A single-frame high bit-rate TDMA scheme (frame length=1 ms) has been selected for the FUL (dimensioned for about 3600 channels at 9.6 kbps), so that each FS capacity requirement is fulfilled with the lowest granularity, although in a fixed way; a single FSs coverage, furthermore, simplifies system architecture and payload design.

In the FDL, a multiple carrier-per-spot solution, at relatively low bit-rate, seemed the most appropriate, in regard of MS complexity and operability. The payload, thus, performs several functions for interfacing the different FUL and FDL schemes including: burst-mode demodulation, frame storing, routing on individual channel basis, speed conversion, on-board modulators-to-spot patching. The FL repeater block diagram is shown in Fig. 1.

After demodulation, a baseband processor routes the individual FUL channels into several low-rate TDM streams (480), each multiplexing 8 channels; this is a trade-off result among number of on-board modulators, bit rate and resolution in channel assignment to spot beams. A switching matrix feeds the TDMs to a phased-array antenna (a conventional multibeam antenna would not allow the same flexibility in RF power allocation). Its switching configuration can be occasionally rearranged to cope with traffic variations.

The same carrier frequency is used for different modulators, patched to different spot-beams. Frequency reuse schemes based upon 3, 4 and 7 sub-bands were evaluated, by considering both the impact on the antenna sidelobes performance requirements and the actual bandwidth saving, in a non uniform traffic environment. The 4-subband solution was chosen, with a bandwidth occupancy of 17 MHz.

About the RL, the regenerative solution was preferred, since it allows to perform on-board some peculiar functions of the Network Coordination Station (NCS), required to manage the network. This would yield the advantages [Colombo et alii, 1985] of reduction of the call set-up delay, simpler network control and saving of NCS/satellite communication links.

The MSs access follows a Single-Channel-Per-Carrier (SCPC) scheme, with the aim to minimize MS complexity and RF power requirements. On-board "multicarrier demodulators" were proposed and studied in detail, embedded in a payload configuration (Fig. 2) which yields a rearrangement capability specular to that of the FL. The OBP converts the FDMA structure of the RUL channel into a single TDM structure in the RDL, such as to optimize the FS equipment and the utilization of RF power.

The system performance is improved by DA techniques so that resources are shared by different traffic sources; Occasional Basis DA (OBDA) and Call Basis DA are alternatively present at various system levels. In particular, OBDA has been provided for associating the modulators (and the multicarrier demodulators) to the various spot beams; this is by far the most critical point for transmission resources efficiency and OBDA can powerfully cope with: forecasting errors on dimensioning data, traffic pattern variations on seasonal basis, peak hour variations due to time shift and different living habits.

3. RECONFIGURATION REQUIREMENTS

Fig. 3 summarizes the steps leading to the re-assignment of the modemodulators to the spots. This is the most important item, which heavily affects on-board complexity and coordination protocols in the network. The crucial point is the rearrangement procedure but a few comments are spent about the other traffic assignment features:

- The traffic demand is estimated by the NCS so as to follow the influence of mobile movement and peak hour variations on the resource needs. This part belongs to the classical estimation theory; it is only pointed out that the NCS knows how many mobiles are active in each spot.
- Once some predefined traffic thresholds are crossed, a decision is taken about the optimal partition of the modulator set among all the spots on the base of the estimated local traffic. Two algorithms have been studied with the objective of achieving a nearly uniform loss probability among the spots.
- On the base of the obtained modulator-to-spot partition, the consequent band portions are assigned to each spot according to the constraints imposed by the chosen frequency reuse strategy. Fig. 3 shows that, in general, the new partition may not be compatible with the available band and the minimum reuse distance; if this happens, a backward step is possibly needed for re-assessing the partition with higher values of loss probability.
- The frequency plan updating can result by management actions consequent to forecasting errors and traffic pattern variations.

As soon as the updated frequency plan is chosen, the passage from the present to the new plan via a rearrangement procedure starts. This is a separation instant between the previous phases (not interacting with the system state) and the step by step procedure leading to the final configuration.

4. THE REARRANGEMENT PROCEDURE

Before describing the procedure, some assumptions are remarked:

- each modulator works on a fixed bandwidth: frequency-agile modulators are a less restrictive particular case;
- only the FL is described; for the specular arrangement of the RL, "modulator" must be changed into "multicarrier demodulator".

Even if the procedure is quite general, it is described in the case of single reuse (double use). Fig. 4 clarifies the adopted notations: natural numbers are chosen for labeling the elementary frequency ranges (carriers) composing the available bandwidth. The modulators working on the same carrier are identified with its label.

Explicitly, the rearrangement consists in updating a frequency plan over S spots by passing from an initial modulator-to-spot configuration $A_1, A_2, \ldots A_S$ to a final one $B_1, B_2, \ldots B_S$, obeying to new traffic needs. According to Fig. 4 notations, A_i and B_i; $i=1,2,\ldots S$ are subsets, non necessarily disjoint, of the set of carrier labels:

$$A_i=\{n_1(i),n_2(i),\ldots n_{m(i)}(i)\}; \quad B_i=\{k_1(i),k_2(i),\ldots k_{r(i)}\}; \quad i=1,2,\ldots S$$

being m(i) and r(i) the initial and final dimensioning of the i-th spot respectively (number of associated modulators). It is assumed that the updated configuration is compatible with the on-board switching capability and the frequency reuse constraints.

Service quality considerations require that no calls in progress are suppressed: the modulators to be moved are partially emptied by the natural end of conversations and by rejection rules for the incoming calls exceeding the final dimensioning. Secondly, even in the "transient" rearrangement phase, a minimum capacity N_i is always guaranteed to the i-th spot:

$$N_i \leqslant \min \{m(i); r(i)\}; \; i=1,2,\ldots S \tag{1}$$

where the sign of equality represents a reasonable condition for N_i.

The procedure has an asynchronous step-by-step behaviour, with each step j characterized by the accomplishment of two basic operations:

$S^{(j)}(n)$: the couple of modulators working on the n-th carrier are Switched on the spots they are assigned to in the final plan;

$R^{(j)}(n)$: Release of the modulators working on the n-th carrier; it is made possible by the occurred switching and has a random duration, owing to the residual conversation times.

During step j, $S^{(j)}(n)$ follows the previous releases and creates further release possibilities compatible with (1). Initially, only a release phase is, in general, possible in those spots whose capacity decreases. During the process evolution, a state can be encountered for which the release of a modulator does not produce a switching possibility; in this case, the residual calls are moved to an extra modulator, temporarily used for carrying voice traffic. The extra modulators work on a bandwidth portion shared by the entire set of spots.

For a general step j, let:

$$A_i^{(j)}, \quad B_i^{(j)}; \quad i=1,2,\ldots S$$

be the sets of modulators still belonging to the initial plan and already switched according to the final plan, respectively. Let $E_i^{(j)}$ denote the number of modulators that can be released in step j, respecting (1). The procedure is initialized (step 0) by considering as already assigned to the final plan the modulators which need no reswitching. Step 0 is then characterized by:

$$A_i^{(0)} \equiv \{k\colon k\in A_i,\, k\notin A_i \cap B_i\}; \; B_i^{(0)}\equiv A_i \cap B_i; \; E_i^{(0)}=m(i)-N_i \quad i=1,2,\ldots S$$

Step j (j$\geqslant$1) is now described with a brief comment on the involved algebraic operations:

a - The set $I^{(j)}$ of the spots where at least one modulator can be

released is found:

$$I^{(j)} \equiv \{i: E_i^{(j-1)}>0\}$$

b - Within $I^{(j)}$, the set of modulators $M_i^{(j)}$ belonging to each i-th spot which can be moved according to the final plan is found:

$$M_i^{(j)} \equiv \bigcup_{\substack{k\epsilon I^{(j)} \\ k\neq i}} [A_i^{(j-1)} \cap A_k^{(j-1)}]; \qquad i\epsilon I^{(j)}$$

In fact, the switching possibility is conditioned on the availability of both homologous modulators.

c - The overall set of the switchable modulators:

$$M^{(j)} \equiv \bigcup_{i\epsilon I^{(j)}} M_i^{(j)}$$

is obtained and an element of $M^{(j)}$, say n_j, is chosen such that at least another couple of modulators can be switched within step j+1. In other words, n_j must produce, after switching, the possibility of releasing another couple of homologous modulators. If this is not possible, n_j is chosen randomly within $M^{(j)}$ and an extra modulator is properly associated in the following step ($M^{(j+1)}\equiv\Phi$).

d - The Release phase starts and, at the end of the residual conversations, the related Switching is performed:

$$R^{(j)}(n_j) \rightarrow S^{(j)}(n_j)$$

e - The new sets $A_q^{(j)}$, $A_r^{(j)}$ and $B_u^{(j)}$, $B_v^{(j)}$ are calculated by moving n_j; q, r obviously represent the couple of spots releasing the modulators n_j; u, v the couple of spots receiving them. In analogy $E_q(j)$, $E_r(j)$, $E_u(j)$, $E_v(j)$ are re-defined.

f - The procedure enters the (j+1)-th step unless the condition $A_i(j) \equiv \Phi \quad \forall i$ is reached which means that the final plan is accomplished.

For brevity, some particular cases are omitted. A general study on the required amount of spare modulators does not exist, but the procedure has been applied to examples with quite dissimilar (old and new) frequency plans and one spare modulator, at most, has been required.

5. CONCLUSIONS

A satellite system for advanced LM services has been described together with the need of incorporating facilities for following the average offered traffic, especially on the mobiles side, where the rather limited capacity does not allow a high trunk group efficiency. To this purpose, a procedure has been conceived and its qualifying points illustrated; a further investigation should be devoted to generalize some heuristic point and to evaluate the procedure efficiency in terms of accomplishment delay.

REFERENCES

ESA 1983. Study of systems and repeaters for future narrowband communications satellites. ESTEC Contract 5484 83/NL/GM/(SC)

G. Colombo, W. Heine, K. Jesche, W. Schreitmuller, F. Settimo 1985. System architecture and management of advanced regional satellites for land mobile applications. Globecom '85, New Orleans, USA

W. Kriedte, A. Vernucci 1985. Advanced regional mobile satellite system for the nineties. Globecom '85, New Orleans, USA

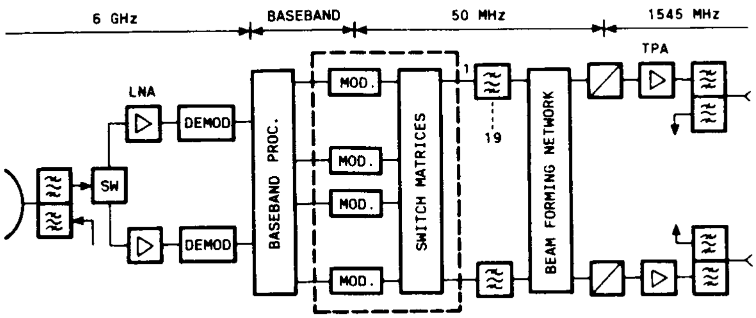

Fig. 1 - Repeater block diagram Forward-link

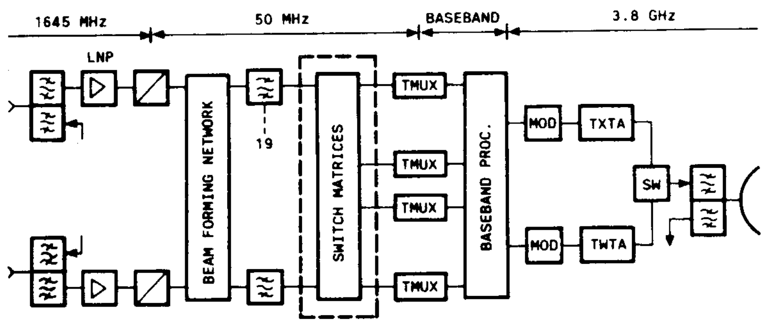

Fig. 2 - Repeater block diagram Return-link

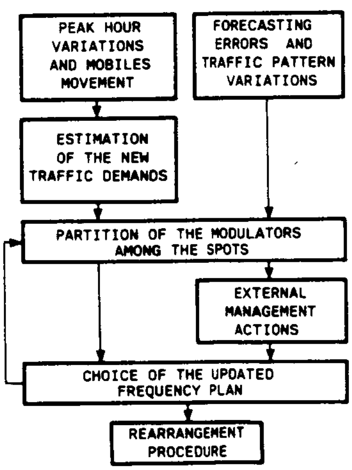

Fig. 3 - Flow diagram of rearrangement operations

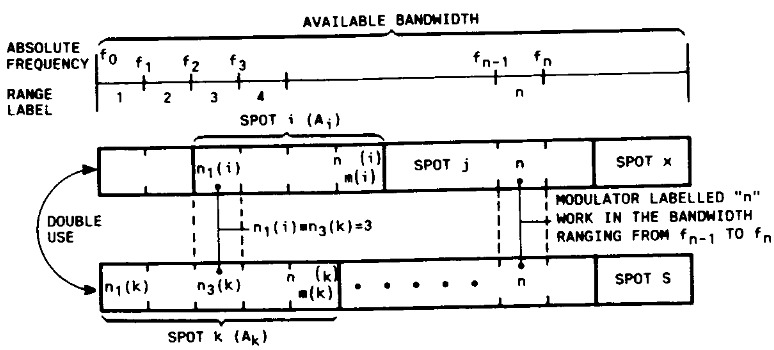

Fig. 4 - Frequency plan with double frequency use